

The Effects of Timbral Cues on Pitch Perception

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Abstract

The current study examined the effects of novel timbres on the accuracy of pitch identification in experienced flutists to improve upon studies by Miyazaki (1989) and Brammer (1951). Flutists with Absolute Pitch and Relative Pitch were presented with two pitch identification tests comprised of five distinct timbre blocks that were deemed to be unfamiliar to them: sinewave, synthesized piano, natural violin, natural clarinet, and mixture of all experimental timbres. In between the two pitch identification tests, a listening session took place to give participants more exposure to the novel timbres in a musical context, with the expectation that increased exposure could affect pitch perception accuracy. Results showed higher accuracy for the synthesized piano timbre as compared to the mixed timbre across participants, an interaction between timbre block type and pitch identification ability, and higher accuracy on the post-listening session test for only the sinewave timbre block as compared to the pre-listening session test. Results indicate that musicians do not rely on musical timbre as a primary cue for pitch perception, but that familiarity with certain aspects of timbre provides an advantage to accurate pitch identifications. Results highlight a learning process musicians undergo in order to become more familiar with unknown timbres. Finally, results also confirm Miyazaki's original claim that Absolute Pitch and Relative Pitch possessors utilize separate mechanisms in order to identify unknown pitch frequencies, regardless of musical timbre.

The Effects of Timbral Cues on Pitch Perception

Musical timbre refers to the acoustical quality of sound that identifies a particular musical instrument or sound source. Timbre gives the flute its characteristic sweet sound, and the cello its distinct dark and warm tone. Yet, the idea of musical timbre remains widely discussed and largely undefined. The American National Standards Institute (1973) defines timbre as the attributes of auditory sensation that allow a listener to distinguish between sounds that have the same pitch and loudness. Although pitch corresponds to the perception of a sound wave's frequency, and loudness corresponds to the perception of a sound wave's amplitude, there is not one distinctive sound attribute that leads to the perception of timbre. The American National Standards Institute's definition of timbre remains vague because it merely references what timbre is not, rather than pointing to a tangible property of sound. Despite the lack of definitive features, timbre remains an essential qualitative aspect to the entire musical experience, from composition, performance, and listening.

Researchers have sought to isolate specific properties that further distinguish timbre from pitch class and loudness. Expanding upon the American National Standards Institute's definition, Saldanha and Corso (1964) suggested that timbre includes the harmonic structure of sound as well as vibrato. Although technically a rapid variation of pitch frequency, vibrato is a technique used by musicians as a way to produce a stronger or richer tone, and thus should be considered a facet of tone quality. Also included within the concept of timbre are the portions of tone duration, or the transients of a sound wave over time: the initial attack of a tone as it begins, the steady-state duration as the tone sustains, and the sound's final decay as the tone tapers. In Saldanha and Corso's study to examine the effects of harmonic structure, transients, and vibrato on the perception of the sound sources, these particular facets of timbre were considered auditory

cues for the judgments of musical tones. The judgments of tones were derived using 10 musical instruments from both the woodwind and stringed instrument families, three different pitch classes, two different playing styles (vibrato or non vibrato), five cuts of tone duration that altered sound wave transients, and two testing sessions. Results of the study showed that when asked to identify the proper musical instrument as the source of the tone participants more easily identified certain instruments such as the flute, clarinet, and oboe over the bassoon or cello. Additionally, participants made more correct identifications for tone that consisted of the initial transient with a short steady state, as well as tones with vibrato as opposed to tones without vibrato. Thus, Saldanha and Corso's study demonstrated that manipulating facets of sound quality, whether it the sound source itself or the properties of the sound wave, have marked effects on the accuracy of perception.

Grey (1977) further expanded the multidimensional definition of timbre to include physical properties of sound. The properties of sound waves Grey considered most salient include the spectral energy bandwidth distribution, the presence or absence of synchronicity in the attacks or decays of musical tones produced by different instruments, and general temporal patterns of sound waves. In Grey's study examining perceptual relationships between 16 different instruments, participants were asked to label the source of an unidentified musical tone. Results showed confusion in the identification of musical instrument identifications due to the alignment of sound qualities in the same musical range. For example, participants occasionally misidentified higher-frequency bassoon tones as a trumpet tones, which points to the similarity in properties of bassoon timbre in the higher register to trumpet timbre in the same range. Thus, Grey demonstrated how the changing of physical properties of sound over the musical range has a direct effect on the resulting perception musical timbre.

Other studies of timbral characteristics have expanded past the identification of musical instruments and sound sources to the realm of pitch class identification. The pitches of piano tones in particular have been found easier to identify than other timbres (e.g., Bachem, 1950; Balzano, 1984; Miyazaki, 1989; Takeuchi & Hulse, 1993). A study by Miyazaki (1989) found that when comparing piano tones to sinusoid waves and synthesized tones played in equal loudness and duration, participants most easily identified the pitches of unidentified tones on the piano, followed by synthesized tones and then pure tones. One of the explanations offered by Miyazaki includes the deep familiarity the participants of the study had with piano tones: all subjects in the study began their musical studies with piano at a formative age.

The suggestion that familiarity with a particular musical timbre aids in pitch identification accuracy has been further supported. A study by Brammer (1951) examined a variety of cues (visual, kinesthetic, tactile, and timbral) musicians use to properly identify pitches and accurately tune musical instruments. When asked to identify and adjust the pitch of a stimulus tone, experienced violinists completed the tasks with a greater accuracy for tones of their own instrument as opposed to tones from a clarinet. After completing the experiment, several violinists expressed the opinion of being “lost” on the clarinet tone trials, while being “confident” in their judgments of violin tones. Encountering the highly familiar violin timbre seemed to calibrate the violinists to know the general extent of their pitch identification accuracy. Thus, manipulating the timbral quality of the stimulus tone had a quantitative effect on the accuracy of pitch identification, as well as a qualitative impact on the general experience of the listener.

Within the realm of pitch perception and identification studies, there has been preliminary research to examine the effects of timbral cues on different pitch identification

abilities, particularly Absolute Pitch (AP). A unique ability attributed to only .01% of the general population, AP is the ability to identify the pitch of an unidentified musical tone without the use of an external reference pitch. The etiology of AP, whether genetic or learned, has not been definitely resolved by researchers, though there has been data to suggest a correlation between the emergence of AP and musical training early on in life (e.g., Miyazaki & Ogawa, 2004; Sergeant, 1969). This ability contrasts with the more common Relative Pitch (RP), the process of using an external reference cue in order to identify an unknown musical tone.

In a study to examine the effects of musical timbre and pitch class region on the accuracy of pitch identifications by AP possessors, Miyazaki (1989) found that AP possessors were superior at identifying the pitch class of an unidentified tone while non-AP possessors were superior to their counterparts at identifying the correct octave of an unidentified musical tone. Miyazaki claimed that timbral cues are merely “auxiliary cues” in the pitch identification process for AP possessors, meaning that individuals with AP rely primarily on the memorization of pitch frequency instead of the timbre or octave location in order to accurately identify the pitch class of a musical tone. The process for individuals who rely on Relative Pitch involves identifying the pitch based off of determining the general octave region, an explanation that leads to the demonstrated differences in ability between AP possessors and non-AP possessors.

Despite the claim that timbral cues are not used primarily in the pitch identification process, the Miyazaki (1989) and Brammer (1951) studies demonstrated significant differences in pitch identification accuracy depending on the manipulations of experimental timbre. As previously mentioned, although the studies revealed higher accuracy in pitch identifications for certain timbres, those particular musical timbres were of high familiarity to the participants who were tested. Miyazaki specifically claims that despite the impact on pitch identification accuracy

by the manipulation of stimulus tone timbre, AP possessors still relied on the memorization of pitch class as the primary cue for identification. Yet, for this hierarchy of cues to be confirmed, the pitch identification process needs to be examined beyond the presentation of very familiar stimulus timbres.

The purpose of the current study is to expand and improve upon the research conducted by Brammer (1951) and Miyazaki (1989) by resolving the experimental confound of timbral familiarity and pitch identification accuracy. Flutists with both Absolute Pitch and Relative Pitch completed two separate pitch identification tests comprised of novel timbres from the two middle octaves of the musical range. The unfamiliar timbres represent several various aspects of sound quality that the participant population would not necessarily encounter or produce frequently: sinusoid waves, synthesized piano, natural violin, and natural clarinet. Participants were asked to identify the unknown pitches of each experimental timbre in separate blocks, as well as randomly selected timbres as stimuli. If musicians are more accurate at identifying unknown pitches of varying timbres as opposed to individual timbres, then timbre can be considered a primary cue in the pitch perception process. Conversely, if musicians are more accurate at identifying unknown pitches from the individual timbres than varying timbres, then musicians are relying on facets other than timbre in the pitch identification process. If musicians with Absolute Pitch ability are more accurate at identifying pitches of unfamiliar timbres than musicians with Relative Pitch, then it can be confirmed that there are separate mechanisms to identifying pitch depending on ability. This would lend support to Miyazaki's claim that musicians with Absolute Pitch rely upon pitch class memorization and musicians with Relative Pitch rely upon octave placement. Finally, if musicians are more accurate at identifying pitches of unfamiliar timbres after gaining exposure through a mid-experimental listening session, then it

may offer more support to the notion that familiarity with timbral qualities aids in the pitch perception process.

Method

Participants

The participants of the current study were 13 flutists, ranging in ability level from intermediate to professional. The average playing experience was 13.19 years. There were 9 Absolute Pitch Possessors and 4 Relative Pitch Possessors.

Materials

Based on properties of timbre as defined by Saldanha and Corso (1964) and Grey (1977) that were deemed to be novel to flutist participants, four different sound sources were selected to represent four experimental timbre types. The first timbre type, synthesized piano, was selected because the synthesized sound source stripped the sound of any natural acoustic properties familiar to flutists. These pitches were derived and recorded from a digital synthesizer using LogicPro software.

The next two timbre types, natural violin and natural clarinet tones, were chosen to represent timbres that flutists would not have familiarity producing. The violin tones were derived from an instrument sound library on LogicPro. Similarly, for the clarinet timbre type, tones were derived from the LogicPro instrument sound library. Lastly, sinewave tones were selected for the last timbre type to represent fundamental frequency, or a baseline of timbral cues. Sinewave tones were derived using Sound Studio software.

The pitches for each type of timbre were taken from two octaves in the middle of available pitch range – from the octave beginning at C4 and ending at C6, spanning 24 tones in total. For each timbre type, 10 different pitches were randomly pre-selected as the stimuli for

each pitch identification test. Thus, 20 of the 24 pitches were utilized for each timbre across the two tests. All stimulus tones were edited to a uniform length of .75 seconds.

For the mid-experiment listening session, eight short melodies were composed using the atonal twelve tone row technique. Four of the melodies were comprised of all twelve tones from C4 to B5, spanning one octave of all possible stimulus tones. Each pitch was only included once in the melody and each pitch was given equal emphasis. Every pitch was given the same rhythmic duration. The other four melodies were comprised of all twelve tones from C5 to B6, spanning the second octave of all possible stimulus tones. Thus, two melodies per experimental timbre were played and recorded.

The program SuperLab 4.0 was used to run the entire experiment on a Macbook Pro computer. Twelve keys on the keyboard were each labeled with one of the possible pitch responses for the participants to press during the experiment (see Figure 1). Participants used a pair of Sony Dynamic Stereo headphones to complete the experiment.

Procedure

Before the experiment began, participants received and signed a consent form. Each participant was then given a pre-experimental survey with the instructions to answer each question to the best of his or her knowledge (see Appendix A).

Participants were informed that they would hear a musical tone, with the task of identifying the correct pitch as rapidly as possible by pressing a corresponding key on the keyboard. They were instructed that entering an answer on the keyboard would prompt the next stimulus tone to play automatically. After hearing the beginning instructions, participants were told to press the space bar when ready to begin the first pitch identification task. The pitch identification test consisted of five blocks of experimental trials. Each block consisted of 10

trials (one stimulus pitch to identify) in randomized order. The first four blocks (presented in randomized order) each consisted of either: synthesized piano tones, sinusoid wave tones, violin tones or clarinet tones. The last block included a randomized mix of all the timbres types. In between each block, there was a 10 second pause. Participants were not given feedback about the accuracy of their responses.

After the first pitch identification test was completed, participants were given the mid-experiment listening session. Participants were told that they would hear eight brief tone row melodies played successively, and were instructed to listen as the melody played. Participants were instructed to press the space bar when ready to begin the listening session. In between each repetition of the melody there was a three second pause.

After the listening session, participants completed the second pitch identification test. As in the first pitch identification test, the first four blocks of timbre types were presented in randomized order and the last block always consisted of a mixture of the timbre types. No feedback was given to the participants regarding the accuracy of their responses.

For the self-identified Relative Pitch possessor participants, a reference tone at A4 (440 Hz) was played prior to hearing each stimulus tone in both pitch identification tests. For the first four blocks, the reference tone was played in the same timbre type as each block of stimulus tones. In the final block of randomized timbres (the fifth block), the reference tone timbre was randomized for each stimulus tone. For example, a synthesized piano stimulus tone could be preceded by a violin reference tone. For the self-identified Absolute Pitch possessor participants, no reference tones were given.

Results

Following completion of the study, the scores of pitch identification accuracy were calculated. For each participant, accuracy scores were computed for each timbre block across all trials, as well as for the pre and post listening sessions.

A repeated-measures ANOVA was run to assess the impact of each experimental timbre on the overall accuracy of pitch identifications ($F(4,48) = 3.94, p = .008$). Across participants, musicians were significantly more accurate at identifying pitches from the synthesized piano timbre as compared to the mixed timbre block, $t(12) = 2.66, p = .021$. There was no significant effect produced by the other experimental timbres (violin, sinewave, or clarinet) compared to the mixed timbre block, indicating that musicians did not utilize timbre as a primary cue for accurate pitch identifications (see Figure 2). A repeated-measures ANOVA was also run to determine the effect of Absolute and Relative Pitch ability on the accuracy of identifications. Results indicated an interaction between participant ability and experimental timbre ($F(4,44) = 5.40, p = .001$). Participants with Absolute Pitch were no different across the timbre blocks but participants with Relative Pitch were different across timbre blocks (see Figure 3). Thus, the two participant populations relied on separate mechanisms when making judgments of pitch frequency, which is further supported by the above finding that higher accuracy for the synthesized piano block was due to the Relative Pitch participants.

Finally, a repeated-measures ANOVA was run to compare the averages of identification accuracy for each timbre before and after participants engaged in a mid-experiment listening session. Post-test comparisons indicated that participants significantly improved from the pre-listening session to the post-listening session only for the sinewave timbre, $t(12) = 3.98, p = .002$

(see Figure 4). There was no effect of Absolute or Relative Pitch ability on participants gaining exposure to unfamiliar musical timbres by engaging in a mid-experiment listening session.

Discussion

The current study was conducted in order to address the experimental confounds of the Brammer (1950) and Miyazaki (1989) studies, and thus examine the perception of unfamiliar musical timbre in a specific population of musicians. Participants completed two pitch identification tests, comprised of unknown pitch frequencies of five different musical timbre blocks: synthesized piano, violin, clarinet, sinewave, and a mixture of all the timbres. The two tests were separated by a mid-experiment listening session designed to provide exposure to the experimental timbres in a melodic context. It was hypothesized prior to the study that if musicians were more accurate at identifying unknown pitches of the mixed timbre block as opposed to individual timbres, then musical timbre may be considered a primary cue in the pitch perception process. It was also predicted that if musicians with Absolute Pitch ability were more accurate at identifying pitches of unfamiliar timbres than musicians with Relative Pitch, Miyazaki's original claim that musicians of AP and RP ability rely on separate mechanisms to identify unknown pitches would gain further support. Finally, it was predicted that if musicians were more accurate at identifying pitches of unfamiliar timbres after gaining exposure to those sounds through a mid-experimental listening session, it would offer more support to the notion from previous studies that familiarity with timbre aids the pitch perception process.

Results from the experiment did not support the first hypothesis. Results did not show a significant difference in the overall accuracy of pitch identifications for the violin, clarinet, and sinewave timbres as compared to the mixed timbre block, suggesting that timbre should not be considered a primary cue in the pitch perception process. Thus, timbre acts as a secondary

perceptual cue to pitch frequency when musicians hear tones of differing quality. The only significant difference of pitch identification accuracy was between the synthesized piano and mixed timbre; in this instance, participants were significantly more accurate at identifying unknown pitches of the synthesized piano block as compared to the mixed block. This indicates that some aspect of the synthesized piano timbre may have had a primary impact on the perception of pitch and accuracy of pitch identifications.

The aspects of the synthesized piano timbre that made it easier to identify for RP possessors point to the presence of a spectrum of musical timbre, which has previously been defined by the multidimensional aspects of sound quality. The unique physical properties of each experimental timbre presented in this study may have contributed to the resulting pitch identification accuracies. Though the specific physical properties of the synthesized piano timbre that contributed to its higher accuracy among participants cannot be determined from the design of this study, a possibility may be its similarities to acoustic piano timbre, which the participants in this study have a high level of experience playing with in a musical setting. Thus, having a deeper familiarity and stronger memory of certain musical timbres may provide an advantage in the pitch identification process.

The results supported the second hypothesis, showing a significant difference between the accuracy of participants with Absolute Pitch and the participants with Relative Pitch for each experimental timbre block. Though this study could not determine the exact mechanism by which musicians with Absolute Pitch or Relative Pitch identify unknown pitch frequencies, results of the current study confirms that the differences in ability between AP and RP musicians extend to the realm of timbre perception. As previously stated, research by Miyazaki (1989) claims Absolute Pitch possessors to rely primarily upon an inherent memorization of pitch

frequencies when identifying unknown musical tones, while the process for Relative Pitch possessors relies on a more general process of octave placement. Due to the results that AP possessors had higher accuracy for all experimental timbres as compared to RP possessors, AP possessors' reliance upon pitch frequency is most logical.

Finally, results offered partial support for the third hypothesis, indicating a significant difference between the pre and post-listening session accuracy scores for only the sinewave timbre block across all participants. There was no significant difference between the pre and post-listening session scores for the other timbre blocks. This suggests that learning the qualities of an unfamiliar musical timbre through melodic exposure may enhance the accuracy of pitch frequency identifications. Though this finding was only demonstrated for the sinewave timbre block, it still provides for support to the concept that the learning process to gain familiarity with musical timbre plays a role in the overall recognition of pitch frequency. Of the four individual experimental timbres presented through the study, this finding fits logically with the sinewave timbre block: sinusoid waves represent the fundamental frequency of a waveform, providing the foundation for musical timbre. In comparison with the other experimental timbres, sinewave tones would be the most unfamiliar to the participant population. These results should not be attributed to the rehearsal effect; the stimulus pitches for each test were pre-selected so as to avoid overlap in the presentation of pitch frequencies across the two tests.

This study represents the first attempt to study the effects of timbre upon pitch perception without relying upon highly familiar timbres as stimuli. However, several improvements can be made. Though the experimental timbres used in the current study were chosen to represent sound qualities that the specific participant population would not have experience hearing or producing on a regular basis, the timbres utilized in the experiment represented only a limited depiction of

the spectrum of timbre. Future research would benefit by expanding the range of musical timbres used as stimuli to include a wider variety of tones; for example, this could include a wider variety of electronic sounds and other instrumental tones that better represent the range of timbral qualities. Furthermore, further research could present similar novel timbres that differ by the manipulation of individual physical properties. Rather than presenting novel tones from completely different sound sources, the waveforms of stimuli could be altered in order to emphasize a particular physical aspect of sound within the tone, such as vibrato or transients. Thus, research could hone in on determining what specific facets of timbre may impact a musician's ability to accurately perceive pitch frequency.

Because this study only focused on one particular population of musicians, future research of timbre perception could expand to a wider demographic of musicians. Given the results that highlighted the learning process of becoming familiar with musical timbre, future research could compare various groups of musicians to determine if timbral qualities impact musicians with particular specialties differently. For example, vocalists may not experience the same learning process associated with timbre as woodwind or string players. Additionally, future research may hone in on how musical timbre affects musicians of various experience by examining this how a musician of limited proficiency may learn the qualities of an unfamiliar timbre in comparison to a musician with a higher level of expertise.

Timbre serves an essential role in the creation, performance, and perception of all musical works. Although the amount of empirical information regarding the determinants of timbre and their effects on pitch perception remains somewhat limited, this study has confirmed the importance of familiarity with timbral qualities for successful pitch frequency identification, as well as musicians' ability to adapt and learn the qualities of unfamiliar timbres. Given this

knowledge, future research may utilize this study's design as the impetus for further probing into the learning process associated with particular aspects of musical timbre, and the mechanism used by musicians of varying abilities to accurately perceive pitch.

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Appendix A

Pre-experimental Survey

1. How many years have you played the flute?
2. Do you have experience playing or performing other instruments?
3. If yes, what are those instruments and for how many years have you played them?
4. In what genres do you have experience playing and performing?
5. To your knowledge, do you have Absolute Pitch (also known as Perfect Pitch)?



Figure 1. The twelve keys of a Macbook Pro keyboard are shown labeled as one complete octave of the musical scale. After hearing each stimulus tone, participants were instructed to press the correct corresponding key to enter an answer.

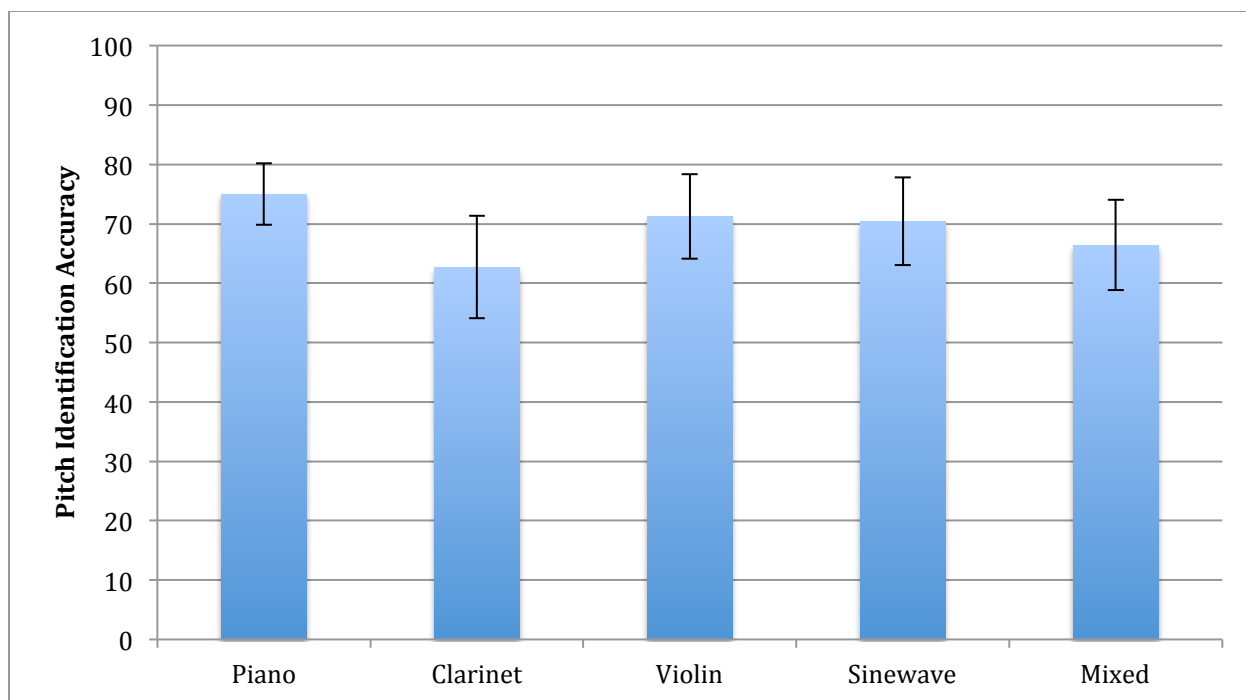


Figure 2. The average pitch identification accuracy across all participants. The percentages of accuracy are shown for each experimental timbre block: synthesized piano, clarinet, violin, sinewave, and mixed timbre.

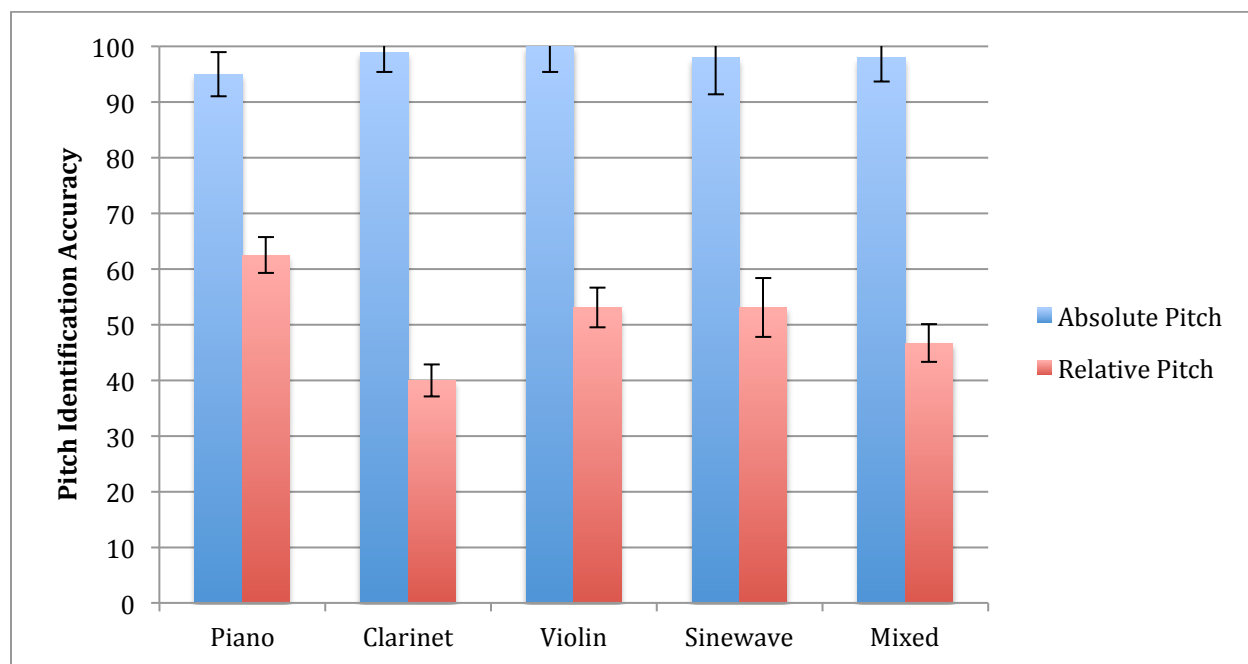


Figure 3. The average pitch identification accuracy categorized by participant ability. The percentages of accuracy are shown for both Absolute Pitch participants and Relative Pitch musicians for each experimental timbre block: synthesized piano, clarinet, violin, sinewave, and mixed timbre.

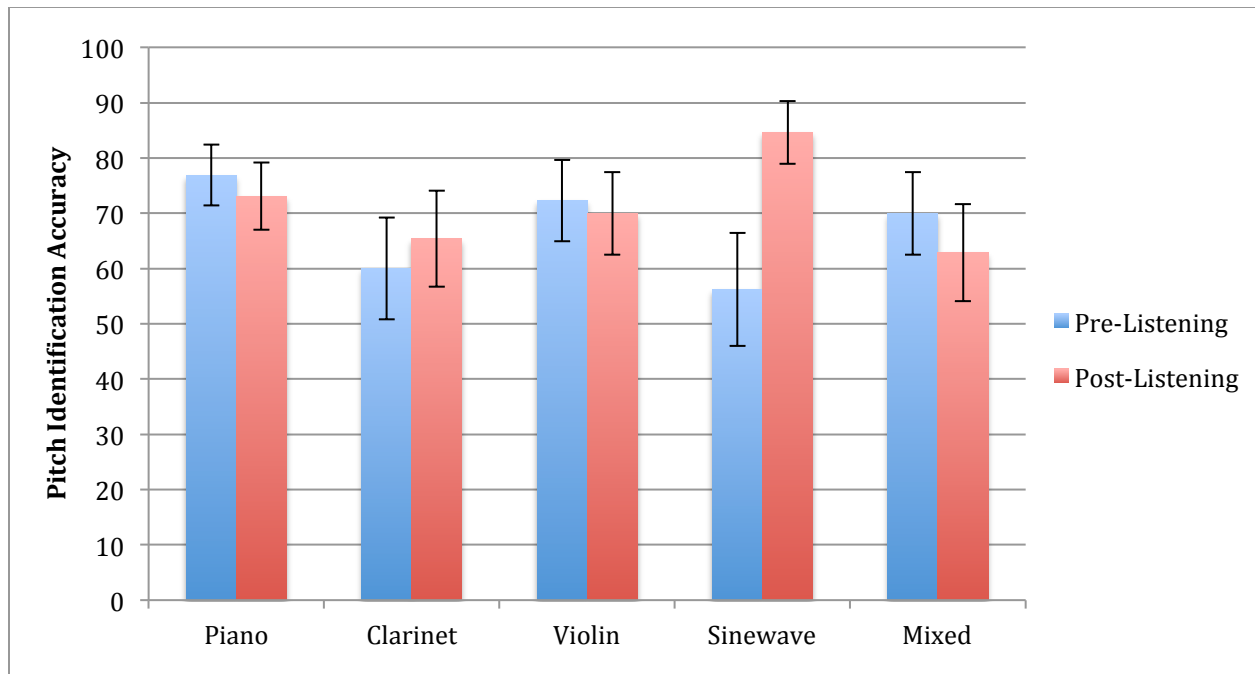


Figure 4. The average pitch identification accuracy across all participants, classified as pre-listening session and post-listening session. The percentages of accuracy for each category are shown for each experimental timbre block: synthesized piano, clarinet, violin, sinewave, and mixed timbre.